Naval Research Laboratory

Monterey, CA 93943-5502

NRL/MR/7543--05-8888

Earth Radii Used in Numerical Weather Models

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September 26, 2005

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
26-09-2005

2. REPORT TYPE
Memorandum Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Earth Radii Used in Numerical Weather Models

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Louis A. Hembree

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory, Code 7543
Marine Meteorology Division
Monterey, CA 93943-5502

8. PERFORMING ORGANIZATION REPORT NUMBER
NRL/MR/7543--05-8888

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Defense Modeling and Simulation Office
1901 N. Beauregard Street, Suite 500
Alexandria, VA 22311-1705

10. SPONSOR / MONITOR'S ACRONYM(S)

11. SPONSOR / MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

In the development of numerical atmospheric models, many simplifying assumptions are made. One of the simplifying assumptions is that the Earth can be represented as a sphere. This assumption greatly simplifies the complexity of the resulting equation set that needs to be solved and makes them more tractable. It also reduces the computational cost. The Synthetic Environmental Data Representation and Interface Specification (SEDRIS) Spatial Reference Model (SRM), ISO/IEC 18026, defines a conceptual model and the methodologies that allow the description, and transformation or conversion, of geometric properties within or among spatial reference frames. This paper serves to document the values used for the Earth's radius by several operational numerical atmospheric models for use in the SRM.

15. SUBJECT TERMS
Modeling and simulation; SEDRIS; Atmospheric modeling

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Louis A. Hembree
a. REPORT	b. ABSTRACT	c. THIS PAGE	UL	7	19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified			(831) 656-4762

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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EARTH RADII USED IN NUMERICAL WEATHER MODELS

1. Introduction

The Synthetic Environmental Data Representation and Interface Specification (SEDRIS) Spatial Reference Model (SRM), ISO/IEC 18026, defines a conceptual model and the methodologies that allow the description, and transformation or conversion, of geometric properties within or among spatial reference frames. The SRM includes support for representation of the Earth including spherical Earth representations. The SRM does not allow for arbitrary values of radius to be used and all values must be included in the standard or incorporated by registration. The objective of this note is to document the values of the Earth's radius used by several atmospheric forecast models and by a radiative transfer model that are included in the initial release of the SRM.

2. Numerical Atmospheric Forecast Models

Numerical weather forecasting models require a closed set of mathematical equations that express an appropriate set of physical laws (Haltiner and Williams, 1980). Also required are initial and boundary conditions and a numerical method for solving and integrating the system of equations in time. The equations used are the equations of motion, the continuity equation, equation of state, the first law of thermodynamics, and an equation to express the conservation of the water substance. This set of equations comprises a set of seven scalar equations and seven unknowns.

Differences in numerical forecast models are due to differences in assumptions, numerical methods used, initialization methods, boundary conditions, and forcing functions. However, one simplifying assumption that they all use is that the Earth can be represented as sphere with a given radius. This assumption greatly simplifies the mathematical complexity of the system of equations and allows the equations to be solved using numerical techniques. The actual value used for Earth's radius is not an integral part of the derivation of the equations other than its order of magnitude. Therefore a particular model could be implemented at different times using slightly different values for the Earth's radius. The atmospheric forecast models covered in this paper are models that are used operationally within the Department of Defense.

2.1 Navy Operational Global Atmospheric Prediction System (NOGAPS)

The Navy Operational Global Atmospheric Prediction System (NOGAPS) model is a global numerical weather prediction model (www.nrlmry.navy.mil/sawmill/index.html; Rosmond, 1998). NOGAPS is run operationally by the U.S. Navy to provide global forecast for DoD and to provide boundary conditions for regional models. NOGAPS has evolved greatly over the years. (Hogan, 2004,personal communication). In 1989, the model was modified to use spherical harmonics as the horizontal basis functions and vertical finite differencing (Hogan 2004,personal communication).

Manuscript approved June 28, 2005.

2.2 Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS)

Regional forecast models are run over a limited region of the Earth and provide higher resolution output than global models. The Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS®[1]) (http://www.nrlmry.navy.mil/coamps-web/web/home; Hodur, 1997, Hodur and Doyle, 1999) is a regional model used by the U.S. Navy to provide regional forecast support for the Navy, Marine Corp, and others since 1998 (Hodur 2004, personal communication). The U.S. Air Force uses a version of the Mesoscale Model 5 (MM5) (http://www.mmm.ucar.edu/mm5/mm5-home.html; Grell *et. al.* 1995) to produce regional forecasts in support of the U.S. Air Force and U.S. Army. It had been used operationally since 1997 (Eckel 2004, personal communication).

2.3 Mesoscale Atmospheric Simulation System (MASS)

The U.S. Air Force Combat Climatology Center (AFCCC) uses an implementation of the regional model Mesoscale Atmospheric Simulation System (MASS) (Bacon *et. al.* 2000: MESO 1999) model as part of the Advanced Climate Modeling and Environmental Simulations (ACMES) System. ACMES is used to perform climtological analysis to produce gridded climatologies and to provide gridded data sets to simulations. Initial operating capability was in 1999 (Walker 2004, personal communication).

3. Radiative Transfer Model

MODerate resolution TRANsmittance (MODTRAN) is a model that is used to calculate the atmospheric transmittance and radiance for ware numbers from 0 to 50,000 cm^{-1} at moderate spectral resolution. MODTRAN was initially released in 1989 (Berk *et. al* 1989) with the latest release being V4.0 released in 1999 (http://www2.bc.edu/~sullivab/soft/modtran4.html).

4. Applicable Earth's Radii

As discussed above, the atmospheric forecast models assume a spherical Earth with a specified radius. The Earth radius value used in COAMPS is 6,371,229 meters (Chen 2004, personal communication), NOGAPS is 6,371,000 meters (Hogan 2004, personal communication), MMR at AFWA is 6,370,000 meters (Eckel 2004, personal communication), and for MASS at AFCCC is 6,371,221.3 meters (Van Knowe 2004, personal communication). These values are summarized in Table 1.

MODTRAN also assumes a spherical Earth, however three different radii are used based on the region (Kneizys *et. al* 1983). MODTRAN divides the Earth into three regions: Tropical, Midlatitude, and Subartic. The corresponding radii are 6,378,390,

[1] COAMPS® is a registered trademark of the Naval Research Laboratory

6,371,230, and 6,356,910 meters respectively (Shirkey 2004,personal communication). These are summarized in Table 1.

In all of the above, the radii are assumed to be exact in the sense that there is no variation of the radius and no error bounds are incorporated into the calculations. The errors that result from the assumption of a spherical Earth are negligible compared to other sources of error and forecast uncertainness.

The standard method for transforming between two representations of the same 3D spatial object is a seven-parameter transformation. The seven parameters correspond to a delta corresponding to the origin shift, 3 rotation parameters, and a scale parameter that corresponds to delta from a scale value of 1. The relationship of the above spherical Earth representations to the WGS84 ellipsoid is such that they have the same origin as defined by the center of mass, scale and orientation. That is the directions of the x, y, and z axes are the same. This implies that all seven parameter in the transformation are zero.

Table 1: Earth radii used for various models in the SRM.

Numerical weather model name	**Application region**	**Radius (meters)**	**Error estimate**	**Relationship to WGS84 ellipsoid**	**Date**
COAMPS®	Global	6,371,229	Exact	Shared origin, orientation, & scale	1997
MASS	Global	6,371,221.3	Exact	Shared origin, orientation, & scale	1999
MM5 (AFWA)	Global	6,370,000	Exact	Shared origin, orientation, & scale	1997
MODTRAN					
Tropical	$-30^\circ \le$ latitude $\le +30^\circ$	6,378,390	Exact	Shared origin, orientation, & scale	1989
Midlatitude	$-60^\circ \le$ latitude $< -30^\circ$ $+30^\circ <$ latitude $\le +60^\circ$	6,371,230	Exact	Shared origin, orientation, & scale	1989
Subarctic	$-75^\circ \le$ latitude $< -60^\circ$ $+60^\circ <$ latitude $\le +75^\circ$	6,356,910	Exact	Shared origin, orientation, & scale	1989
NOGAPS	Global	6,371,000	Exact	Shared origin, orientation, & scale	1988

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